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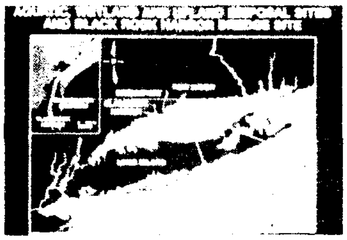

LONG-TERM EFFECTS OF DREDGING
OPERATIONS PROGRAM

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INTERIM REPORT

LONG-TERM EVALUATION OF PLANTS AND ANIMALS COLONIZING CONTAMINATED ESTUARINE DREDGED MATERIAL PLACED IN BOTH UPLAND AND WETLAND ENVIRONMENTS

by

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Contaminated sediment was dredged from Black Rock Harbor, Connecticut, in October 1983 and placed in aquatic, upland, and wetland environments as part of the Field Verification Program (FVP), conducted during the period 1981-1986. Laboratory tests were conducted on the sediment prior to dredging to evaluate potential contaminant mobility under each of the disposal alternatives. Prior to dredging for upland disposal and wetland creation at the FVP field site, upland tests (i.e., plant and earthworm bioassays) and wetland tests (i.e., plant, sandworm, snail, and mussel bioassays) were conducted. Laboratory test results were subsequently field verified at the field test site at Tongue Point, Bridgeport, CT. The results of the upland disposal and wetland creation portions of the FVP, and the changes occurring since completion of the FVP for each disposal environment, are summarized herein. The emphasis of this report is on the contaminant mobility of heavy metals. This interim report includes data collected through 1989. Contaminant mobility and the progressive development of the upland and wetland ecosystems at this site will be evaluated until September 1995.

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Preface

This work was conducted as part of the Long-Term Effects of Dredging Operations (LEDO) Program, which is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE). The LEDO Program is managed under the Environmental Effects of Dredging Programs (EEDP) at the US Army Engineer Waterways Experiment Station (WES). Dr. Robert M. Engler is manager of EEDP and LEDO. Technical Monitors for LEDO are Mr. Joe Wilson, CECW-OD, and Mr. David B. Mathis, HQUSACE.

The study was conducted and the report prepared by Mr. Dennis L. Brandon, Statistician; Dr. Charles R. Lee, Soil Scientist; Dr. John W. Simmers, Research Biologist; and Mr. John G. Skogerboe, Physical Scientist, of the Contaminant Mobility and Regulatory Criteria Group (CMRCG), Ecosystem Research and Simulation Division (ERSD), Environmental Laboratory (EL), WES, and by Dr. Gerould S. Wilhelm, Botanist, of The Morton Arboretum.

The work was conducted under the supervision of Dr. Lloyd H. Saunders, Chief, CMRCG; Mr. Donald L. Robey, Chief, ERSD; Dr. John Harrison, Chief, EL; and Dr. George Ware, Director, The Morton Arboretum.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (US liquid)	3.785412	liters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.000112	kilograms per square meter
pounds (mass) per acre	1.121	kilograms per hectare
square feet	0.09290304	square meters
square miles	2.589998	square kilometers
tons (metric) per hectare	0.10	kilograms per square meter

Summary

Long-term evaluation of ecosystems developing on dredged material disposal sites has been accomplished on some of the marsh creation sites established under the Dredged Material Research Program. These sites were not classified as contaminated, and their evaluations did not consider contaminant mobility. Disposal site monitoring is normally conducted during the operational phase of a dredging/disposal project, and perhaps during the first year after completion of the dredging/disposal activity. While changes in contaminant mobility may occur over the long term, no interim or long-term evaluation data are available to document such changes.

Contaminated sediment was dredged from Black Rock Harbor, Connecticut, and placed in aquatic, upland, and wetland environments as part of the Field Verification Program (FVP). Laboratory tests were conducted on the sediment prior to dredging to evaluate the potential contaminant mobility under each of the disposal alternatives. This interim report examines the contaminant mobility of heavy metals into plants and animals in the upland and wetland field sites. Additional analyses of polycyclic aromatic hydrocarbons and polychlorinated biphenyls will be included in the final report.

Upland control plots of unamended dredged material were barren of vegetation from 1985 through 1989. Six years after placement in an upland disposal environment, unamended estuarine dredged material decreased in salinity to <1 ppt. However, soil pH remained extremely acidic at 3.4, keeping toxic metals soluble and available to plants that attempted to colonize the unamended dredged material. In contrast, amended dredged material became vegetated. Soil and vegetation-dwelling macroinvertebrates have begun to colonize these plots, and food webs involving vertebrates have evolved.

During the FVP, as predicted, *Spartina alterniflora* did not survive in an upland environment. Results from FVP tests on *Sporobolus virginicus* were compared with 1988 and 1989 *Agrostis alba* (redtop) tissue concentrations. Redtop zinc, cadmium, and chromium were designated "elevated." These designations were consistent with the FVP laboratory bioassay and field test results. Redtop nickel and lead concentrations were also designated elevated. The nickel designation was consistent with

the FVP lab bioassay, while the lead designation was consistent with the FVP upland field test. The redtop copper concentration was not categorized since no consistent trends exist. Future evaluations will attempt to obtain sufficient animal biomass for chemical analysis.

Of the soil invertebrates collected, Gastropoda, Orthoptera, and Coleoptera are the best candidates for future testing. If sufficient biomass cannot be obtained for chemical testing, earthworms will be used to assess contaminant mobility in this environment. This bioassay will also address the long-term accuracy of the upland animal bioassay. Vertebrate animals, both birds and mammals, are using the site for feeding and cover. Vertebrates have not been collected for analysis since none of the species observed is restricted to the FVP portion of the Tongue Point site, Bridgeport, CT.

Both the native and introduced *Spartina* plants are currently thriving in the wetland environment. Concentrations of FVP *Spartina* were compared to 1988 and 1989 field *Spartina* tissue concentrations. The 1988 and 1989 *Spartina* concentrations are generally no greater than those measured in the naturally occurring *S. alterniflora* at Tongue Point prior to wetland creation or those measured in nearby naturally occurring salt marshes. Copper and chromium tissue concentrations are possible exceptions. These metal concentrations tended to be higher in 1985, 1986, 1988, and 1989. Future wetland evaluations will include sediment and plant tissue analyses. The sediment analysis will identify any changes in sediment composition since 1983. Subsequent *S. alterniflora* analysis will include organics as well as metal contaminants. These analyses will address contaminant uptake by wetland plants as well as the long-term accuracy of the wetland plant bioassay. Snails collected in the field in 1988 and 1989 had copper, cadmium, and mercury concentrations lower than the FVP control animals. Additional evaluations will include water quality and animal contaminant uptake. Mussels will be used to evaluate site water quality. Subsequent analysis of snail tissue will provide further insight into contaminant mobility from sediment into animal food webs associated with this wetland environment.

In both the upland disposal and wetland creation field sites, plant and animal interrelations are developing. The extent of the populations and the species compositions of the ecosystems may require management procedures if unanticipated routes of contaminant mobility develop. Continued evaluation will better define the extent and nature of contaminant mobility at the FVP site where contaminated estuarine dredged material was placed simultaneously in an upland and a wetland environment. This evaluation should include the contaminant mobility of organics into plants and animals in both environments. The development of the upland and wetland ecosystems at this site will be evaluated through September 1995.

1 Introduction

Purpose

This report summarizes the data collected between 1983 and 1989 which relate to plant and animal communities colonizing the upland and wetland disposal sites of the Field Verification Program (FVP). The management of contaminated dredged material and the mobility of contaminants from the dredged material into plants and animals are also described.

Background

Long-term evaluation of ecosystems developing on dredged material disposal sites has been accomplished on some of the marsh creation sites established during the Dredged Material Research Program (Herner & Company 1980). These sites were not classified as contaminated, and their evaluations did not consider contaminant mobility. Contaminated dredged material has been evaluated only on a short-term basis, such as laboratory tests prior to dredging and disposal operations and during the operational phases of some confined disposal facilities. Monitoring is normally conducted during the operational phase of a dredging/disposal project and perhaps during the first year after completion of the dredging/disposal activity.

While it may appear that changes in contaminant mobility occur over the long term, no interim or long-term evaluation data are available to document such changes. The long-term effects of contaminated estuarine dredged material placed in upland and wetland environments on the colonization of plants and animals and the mobility of contaminants into those plants and animals are the subjects of this report.

Field Verification Program

Contaminated sediment was dredged from Black Rock Harbor, Connecticut, in October 1983 and placed in aquatic, upland, and wetland environments as part of the FVP, which was conducted during the period 1981-1986 (Peddicord 1988). Laboratory tests were conducted on the sediment prior to dredging to evaluate the potential contaminant mobility under each of the disposal alternatives. Prior to dredging for upland disposal and wetland creation at the FVP field site, upland tests (i.e., plant and earthworm bioassays) and wetland tests (i.e., plant, sandworm, snail, and mussel bioassays) were conducted. Laboratory test results were subsequently field verified at the field test site at Tongue Point, Bridgeport, CT (Figure 1).

The results of the upland disposal and wetland creation portions of the FVP, and the changes occurring since the completion of the FVP for each disposal environment, are summarized herein. The emphasis of this report is on the contaminant mobility of heavy metals. This interim report includes data collected through 1989. Contaminant mobility and the progressive development of the upland and wetland ecosystems at this site will be evaluated until September 1995.

2 Upland Environment

Upland Site History

Prior to construction, the field site was used as an open dump. The debris consisted mainly of urban building rubble (i.e., bricks, cement, and rebar). Both upland and wetland ecosystems were present, as were assortments of flora and fauna characteristic of each. During the initial field survey conducted in July 1983, plants were collected along four transects that included both upland and wetland areas. *Phragmites australis* (common reed), *Solanum dulcamara* (nightshade), *Robinia pseudoacacia* (black locust), and *Populus deltoides* (cottonwood) were collected, and the tissues were analyzed for metals (Table 1).

The observed concentrations of heavy metals were typical of any urban vacant lot in the northeastern United States containing building rubble. Both plant species and the general rubble constituents were typical of the neighborhood adjacent to Tongue Point. The elevated cadmium concentrations in *P. deltoides* are indications of potential contaminant mobility. These trees have been shown to significantly enrich the cadmium concentrations in leaf litter, thereby increasing the cadmium concentrations in many soil invertebrate species (Stafford et al. 1991). The field survey described the abundance and diversity of the animal species onsite. These include rats, insects, snakes, and several species of birds (Stewart et al. 1983).

Construction

All grading and dike construction was performed with conventional equipment. The total surface area was approximately 2,600 m^2 (Figure 2). A weir with adjustable risers was installed to control overflow. Peddicord (1988) provides additional information on site design and preconstruction evaluations. Characteristics of the Black Rock Harbor sediment are presented in Table 2. Folsom et al. (1988) provide further discussion of upland construction.

Physicochemical Changes in Dredged Material

Placement of Black Rock Harbor sediment in an upland disposal environment resulted in pronounced changes in some attributes of the contaminated sediment. Following upland disposal, the dredged material dried and oxidized. The pH of the dredged material dropped from 7.6 in 1983 to 3.2 by the end of the FVP in 1986 (Table 3). This substantial decrease in dredged material pH was presumably a result of the decomposition of organic matter, the oxidation of sulfide, limited pH buffering capacity in Black Rock Harbor sediment, low percent $CaCO_3$ equivalent, and the acid rainfall of pH 4.0 to 4.5 at the field site location (Skogerboe et al. 1987).

This substantial decrease in the pH of the dredged material enhanced the solubility and availability of the toxic metals—zinc, cadmium, copper, nickel, chromium, and lead (Folsom et al. 1988). The harsh conditions of extreme acid pH, excess soluble toxic metals, and excess salinity resulted in the death of all plant species planted. Concomitantly, there was no colonization of the site by animals. After placement in an upland environment, control plots of unamended dredged material have been barren of vegetation from 1985 through 1989 (Figures 3a and 3b), even after repeated attempts to establish acid-tolerant, salt-tolerant, and/or metal-tolerant plant species.

Upland Plants

The FVP laboratory test predicted that *Spartina alterniflora* (smooth cordgrass) would not grow in unamended dredged material in the field. This was verified, as no *S. alterniflora* plants survived in the unamended dredged material. The lab test also predicted that plant species might grow in amended material. *Sporobolus virginicus* survived in amended material in the lab as well as the field (Folsom et al. 1988). Field tests were conducted using soil amendments (Table 4) such as lime, manure, and sand plus limestone gravel to stabilize the dredged material, control erosion, and alter the dredged material for plant and animal colonization.

These soil amendments were selected to counteract the extensive chemical and physical changes that occurred when Black Rock Harbor dredged material dried and oxidized. As the dredged material organic matter oxidized upon drying, organic acids were produced to lower the pH, and organic-bound metals were released. As sulfides oxidized, sulfuric acid was produced to lower the soil pH, and sulfide-bound metals were released as soluble sulfate metals (Lee et al. 1991).

Since sediment $CaCO_3$ content was low at 1.0 percent, limited buffering of sediment pH occurred, and the pH dropped from 7.6 to 3.2. Lime was added to neutralize the acids generated upon drying and oxidation of the dredged material. Manure was added to replace the organic matter oxidized; to increase surface metal adsorption; to immobilize metals released when organic-bound metals were oxidized; and to ameliorate the toxic effects of excess salinity. Before exposure to the contaminated dredged material, a layer of sand and gravel was selected to provide a nontoxic microhabitat and a substrate for germination of seeds and establishment of plants. Coarse limestone gravel was placed on the surface to neutralize acid rainfall that might impact the plot and to provide release of limestone-neutralizing material over the longer term.

The site was partitioned into plots, with each amendment being assigned randomly to four plots (Figure 4). The lime and lime + manure amendments were surface broadcast; then, a surface layer of sand and limestone gravel was placed over the lime and manure. A selection of acid-, salt-, and metal-tolerant plant species were planted on the amended dredged material in an attempt to establish vegetation. Table 4 and Figures 5-7 show the plant and amendment combinations during four attempts to vegetate this disposal site. All plant species were broadcast as seeds except *Paspalum vaginatum* and *S. virginicus*, which were plugged.

Amendments of lime, lime + sand + gravel, lime + manure, and lime + manure + sand + gravel resulted in vegetation becoming established on the dredged material (Table 5). Of the plant species seeded on the field plots, only *Agrostis alba* (redtop) became permanently established. *Phragmites australis* had extended its rhizomes from the upland containment facility dike of construction rubble onto some of the plots. Other plant species observed on the plots in 1989 are typical Eurasian species and urban weeds that probably originated from seed sources in the Bridgeport area (Table 5).

The best vegetative establishment was observed on the lime + manure + sand + gravel amended plots in 1985 (Figure 8a). In 1989, these plots were almost completely covered with vegetation (Figure 8b, Table 5). Apparently, the sand + gravel cover allowed rainfall to soak the surface-applied lime and manure into the surface of the dredged material, enhancing plant growth and establishment. The lime and lime + manure plots showed 51 and 28 percent cover, respectively, in 1989 (Table 5). However, subplots receiving an additional application of 56 metric tons per hectare of lime and rototilling resulted in a soil pH of 4.4 and 4.1 and produced 96 and 99 percent vegetative cover in 1989 (Table 5). Mixing lime into the surface material appeared to have greatly improved plant growth and vegetative cover.

Vegetative cover plays a significant role in improving surface runoff water quality (Skogerboe and Lee 1987). Vegetation also decreases windborne and waterborne erosion, aids in dewatering the site, prevents pools of standing water, and provides an aesthetically pleasing cover. Continued long-term evaluation of the FVP site will identify plant species that maximize the properties listed above and minimize contaminant mobility.

Comparison to FVP Upland Plant Results

The FVP laboratory and field upland plant bioassay results are shown in Table 6 and are summarized below. When mean concentrations are statistically different, it can be concluded that one is higher than the other (i.e., elevated). The FVP *S. virginicus* lab test results indicated that plant contents of zinc, cadmium, and chromium would be elevated; field results showed they were elevated. The laboratory tests also indicated that nickel and copper would be elevated; however, field tests showed they were not elevated. Lab tests indicated low lead contents. However, field-grown plants had higher lead contents (Folsom et al. 1988).

Sporobolus virginicus survived only one growing season in the field. It would have been instructive to compare FVP results with current trends using *Sporobolus* as an index plant. However, the plant species that survived onsite are different from those evaluated in the FVP. Plant tissues from the dominant species were collected in 1988 and 1989.

The chemical analyses of *A. alba* tissues are presented in Table 7. Redtop mean concentrations of zinc (Zn), cadmium (Cd), and chromium (Cr) were of the same general magnitude as the FVP results. Hence, one might designate these concentrations as "elevated." The nickel (Ni) concentrations were of the same general magnitude as those designated as elevated during the FVP. The copper (Cu) concentrations do not have the same relative magnitude from treatment to treatment or from year to year. Therefore, classifying Cu concentrations would be impractical. Redtop lead (Pb) concentrations are higher than the FVP field results and should be designated as elevated. Differences between the FVP results and the 1988 and 1989 concentration trends could be due to plant physiology and/or site conditions.

Contamination of Plants

Lee et al. (1991) compiled plant tissue information from a number of sources to indicate the demonstrated effects of contaminants on plants (Table 8). Using these data as guidance, the *A. alba* tissue contents of zinc were within the normal range of 15 to 150 µg/g found in agricultural crops. Plant cadmium concentrations were equal to or slightly above the normal range, and substantially below the critical content level of 8 µg/g (Table 8). Copper concentrations appear to be either in the normal range or slightly elevated above phytotoxic levels in some samples. However, there is considerable variability in the analyses of the elevated samples. Future sampling and evaluation will be conducted to produce more precise results.

Nickel concentrations were equal to or slightly above the critical content level. Chromium concentrations were above normal in 1988, and three of the four amendments showed tissue content above phytotoxic levels in 1989. Lead concentrations were equal to or slightly above the normal range. The only mercury reference tissue concentration available was 1.0 µg/g in wheat kernels as an action level for human foodstuff. Mercury contents of *A. alba* were approximately one tenth this action level, and therefore should not be of concern.

Future Upland Plant Evaluation

Future site evaluations will include surface and groundwater testing as well as field bioassays. Current surface runoff water quality on the FVP site will be quantified with the rainfall simulation system of the US Army Engineer Waterways Experiment Station. Existing groundwater wells will be sampled biennially. Additional plant bioassays will be conducted. These tests will provide insight into the long-term accuracy of this bioassay. If *A. alba* remains a dominant species, it will be used in subsequent years to evaluate contaminant mobility at this upland site. *Agrostis alba* will also be collected at reference locations near Tongue Point.

Upland Animals

The upland animal bioassay predicted that earthworms would not survive in this dredged material under oxidized conditions. Through 1986, earthworms could not survive on this dredged material (Folsom et al. 1988). Presently, control plots devoid of vegetation contain few animals (Table 9). In particular, no soft-bodied animals (i.e. slugs) were observed or collected from this environment. Those animals that were collected or observed were transient foraging arthropod species.

In contrast, establishment of vegetation on the amended dredged material enhanced the abundance and diversity of animals. Numerous species of macroinvertebrates are associated with the plant cover and the leaf litter layer of the soil. The animals observed (Table 9), while relatively abundant, have provided too little biomass per species for chemical analysis. Consequently, no data are available to evaluate contaminant uptake.

Future Upland Animal Evaluation

Future evaluations will attempt to obtain sufficient biomass for chemical analysis. Of the soil invertebrates collected, Gastropoda, Orthoptera, and Coleoptera are the best candidates for future testing. If sufficient biomass cannot be obtained for chemical testing, earthworms will be used to assess contaminant mobility in this environment. This bioassay will also address the long-term accuracy of the upland animal bioassay.

Vertebrate animals, both birds and mammals, are using the site for feeding and cover. Vertebrates have not been collected for analysis since none of the species observed is restricted to the FVP portion of Tongue Point. These animals could migrate into surrounding areas for feeding and cover. This makes it difficult to relate animal tissue contents to the FVP site.

3 Wetland Environment

Wetland Site History

The initial field survey of Tongue Point also included wetland areas. Plants were collected along several transects. The species collected included *P. australis*, *Solidago sempervirens* (seaside goldenrod), *Distichlis spicata* (spikegrass, saltgrass), *Juncus gerardii* (blackgrass), *Limonium carolinianum* (sea lavender), *Spartina patens* (saltmeadow grass), and *S. alterniflora* (Table 1). The *Spartina* metal contents were in the range of natural marsh *S. alterniflora* plants in the northeastern United States (Simmers et al. 1981). The field survey also listed animals that inhabited the stagnant and intertidal ponds. These included fish, shrimp, sandworms, snails, mussels, clams, and several species of crabs (Stewart et al. 1983).

Construction

Prior to construction, *S. alterniflora* was collected from 650 m^2 of the wetland. The construction involved the excavation of material to achieve the desired elevation. The total surface area was approximately 7,060 m^2. A weir was installed to allow an interchange of tidal flow with tidal pools within the Tongue Point site. At high tide, the water level within the site reaches a depth of approximately 0.3 m (Simmers et al. 1989). Simmers et al. (1989) provide further discussion of wetland construction.

Wetland Plants

Spartina alterniflora and *Sporobolus virginicus* were used in laboratory and field bioassays. Laboratory tests indicated that the contaminated sediment was not toxic to the salt marsh plants *S. alterniflora* or *S. virginicus* when placed in a wetland environment. *Spartina* survived well in the field test. However, *Sporobolus* did not survive in the field (Simmers et al. 1989).

Creation of a salt marsh wetland with Black Rock Harbor dredged material has been successful. One half of the created FVP wetland was planted with *S. alterniflora* supplied by Environmental Concern, St. Michaels, MD (Figure 2). Initial growth of Environmental Concern's transplants on the FVP field site appeared to be slow until 1986; then, in 1987, 1988, and 1989, the vegetation on the created wetland gradually expanded until the side planted with Environmental Concern's transplants was covered by a dense stand of *S. alterniflora* (Figures 9a-9f). The highest biomass production was observed in 1987 (Table 10).

The other half of the wetland was planted with native *S. alterniflora* collected prior to construction of the dredged material-created wetland. These transplants were slower to grow in 1986 and 1987 but exceeded the Environmental Concern's transplants in 1988 and 1989 (Table 10). However, the native plants did not cover a large portion of the wetland (Figure 9f, left side).

As the wetland extended across the marsh creation site, the most robust plant growth was observed in the vicinity of the outer edge of the marsh as it expanded to vegetate the more open areas (Figure 9d). Consequently, the 1988 and 1989 sample data reflect an area of wetland behind the advancing edge of the marsh. This was especially true for the Environmental Concern's transplanted wetland. These biomass yields have been in the range of naturally occurring salt marshes in the northeastern United States (Simmers et al. 1981). Simmers' samples included robust plants on the edge of *S. alterniflora* salt marshes when such plants were present.

Comparison to FVP Wetland Plant Results

The FVP laboratory and field tests with *Spartina* are presented in Table 11 and summarized below. When mean concentrations are statistically different, it can be concluded that one is higher than the other (i.e. elevated). Zinc content of laboratory-grown plants was not different from that of the 1985 field-grown plants, but was significantly lower than that of the 1986 field-grown plants. Cadmium content of lab-grown plants was significantly greater than the 1985 and 1986 field-grown plants. Copper and nickel contents of lab plants were not significantly different from the 1985 and 1986 field-grown plants. Chromium and lead contents of lab-grown plants were significantly lower than the 1985 field-grown plants, but not significantly different from the 1986 field-grown plants (Simmers et al. 1989).

Use of the FVP results (i.e. laboratory and 1985 and 1986 field data) to indicate elevated concentration levels provides a method to evaluate the 1988 and 1989 *Spartina* data (Table 12). This evaluation is presented in Table 13 and summarized herein.

In Table 11, the 1986 field mean zinc concentration was 19.2 $\mu g/g$. This value was statistically different (i.e. elevated) from the laboratory concentration of 12.1 μg/g. The 1986 mean zinc concentration was designated as elevated (Table 13). The laboratory mean zinc concentration is designated "not elevated." The 1985 field mean zinc concentration (13.5 μg/g) is not statistically different from 19.2 or 12.1. It is designated "possibly elevated." Since the 1988 and 1989 (Table 12) mean zinc concentrations exceed 19.2, these concentrations are given the same designation as the 1986 mean zinc concentration (i.e., elevated).

The laboratory mean cadmium concentration (0.041 μg/g, Table 11) is designated as elevated in Table 13. Since the 1988 and 1989 (Table 12) mean cadmium concentrations exceed 0.041, these concentrations are also designated as elevated in Table 13. The FVP copper and nickel mean concentrations (Table 13) were not given a designation since none of tests was statistically different. The 1988 and 1989 copper concentrations appear to be higher than those from the laboratory and 1985 and 1986 field tests. The 1988 and 1989 nickel concentrations appear to be higher than the laboratory and 1986 field tests but lower than the 1985 field test.

The 1986 mean chromium concentration (6.17 μg/g, Table 11) is designated "possibly elevated" in Table 13 (i.e., not statistically different from the elevated concentration, 10.4, or the nonelevated concentration, 0.274). Since the 1988 and 1989 (Table 12) mean chromium concentrations fail to exceed and exceed 6.17, respectively, these concentrations are designated as not elevated and possibly elevated. The 1986 mean lead concentration (0.945 μg/g, Table 11) is designated as possibly elevated in Table 13 (i.e., not statistically different from the elevated concentration, 3.45, or the nonelevated concentration, 0.237). Since the 1988 (Table 12) mean lead concentration exceeds 0.945, it is designated as possibly elevated. The 1989 (Table 12) mean lead concentration (3.8) is designated as elevated.

Contamination of Salt Marsh Wetland Plants

The 1988 and 1989 plant tissue concentrations are generally no greater than those measured in the naturally occurring *S. alterniflora* at Tongue Point prior to wetland creation or those measured in nearby naturally occurring salt marshes (Table 12). Copper and chromium tissue concentrations are possible exceptions. These metal concentrations tended to be higher in 1985, 1986, 1988, and 1989.

Future Wetland Plant Evaluation

Future site evaluations will include sediment and plant tissue analysis. The sediment analysis will identify any changes in sediment composition since 1983. Subsequent *S. alterniflora* analysis will include organics as well as metal contaminants. These analyses will address contaminant uptake by wetland plants as well as the long-term accuracy of the wetland plant bioassay. *Sporobolus* will not be used in future evaluations.

Wetland Animals

Animal bioassay results from static and tidal simulation tests indicated that tidal simulation procedures are superior to static tests for measuring uptake by organisms in the intertidal wetland habitat. Comparison of FVP field-collected animal data with laboratory tidal bioassay suggests that tidal simulation bioassay procedures are overpredictive of polychlorinated biphenyl (PCB) congener, hexachlorobenzene, and DDE bioaccumulation. No clear pattern between laboratory and field tests emerged for metals (Simmers et al. 1989). Native sandworms (*Nereis succinea*) colonized the wetland in 1986 (Figure 10). Since 1986, fish, crabs, and snails have been observed in the FVP-created wetland. Table A1 of Simmers et al. (1989) lists the bird and mammal species observed on this site in August 1984.

Contamination of Salt Marsh Wetland Animals

Snails *Ilyanassa* (=*Nassarius*) *obsoleta* were collected in 1988 and 1989 and have been analyzed for contaminant contents (Table 14). The 1988 and 1989 copper, cadmium, and mercury concentrations are less than the respective concentrations of FVP laboratory control snails. It was noted that *I. obsoleta* typically contained elevated levels of copper, possibly because of the high copper concentration in the respiratory pigment, haemocyanin (200 atoms per mole). Zinc, nickel, chromium, and lead concentrations were not measured in the FVP control animals. The polycyclic aromatic hydrocarbon (PAH) and PCB analyses are not currently available and will be evaluated in the final report. Cadmium and copper tissue concentrations in native sandworms (*Nereis succinea*) were 6.6 and 443 ppm, respectively.

Future Wetland Animal Evaluation

Future site evaluations will include water quality and animal contaminant uptake. Mussels will be used to evaluate the site water quality. Subsequent analysis of snail tissue will provide further insight into contaminant mobility from sediment into animal food webs associated with this wetland environment. Snail bioassays will also address the long-term accuracy of the animal bioassay. Reference animal data will be collected for comparison to the FVP data.

4 Interim Conclusions

Upland control plots of unamended dredged material were barren of vegetation from 1985 to the present time. Six years after placement in an upland disposal environment, unamended estuarine dredged material decreased in salinity from a high of 29 ppt after drying out to <1 ppt. However, soil pH remained extremely acidic at 3.4, keeping toxic metals soluble and available to plants that attempted to colonize the unamended dredged material. In contrast, amended dredged material became vegetated. Soil- and vegetation-dwelling macroinvertebrates have begun to colonize these plots, and food webs involving vertebrates have evolved.

During the FVP, as predicted, *Spartina alterniflora* did not survive in an upland environment. Results from FVP *Sporobolus virginicus* tests were compared to 1988 and 1989 redtop tissue concentrations. Redtop zinc, cadmium, and chromium were designated as elevated. These designations were consistent with the FVP laboratory bioassay and field test results. Redtop nickel and lead concentrations were also designated as elevated. The nickel designation was consistent with the FVP lab bioassay, while the lead designation was consistent with the FVP upland field test. The redtop copper concentration was not categorized since no consistent trends exist. Upland animals did not yield sufficient biomass to allow chemical analysis. Therefore, contaminant mobility into upland animals will be addressed in the final report.

Both the native and introduced *Spartina* plants are currently thriving in the wetland environment. The FVP *Spartina* concentrations were compared with 1988 and 1989 *Spartina* tissue concentrations. The 1988 and 1989 zinc and cadmium concentrations were designated as elevated. The 1988 and 1989 copper and nickel concentrations were not assigned a designation. The 1988 and 1989 chromium concentrations were designated "not elevated" and "possibly elevated," respectively. The 1988 and 1989 lead concentrations were designated "possibly elevated" and "elevated," respectively. Neither FVP lab bioassay or field tests predicted the current concentration levels of copper and cadmium in wetland plants.

Snails collected in the field in 1988 and 1989 had copper, cadmium, and mercury concentrations lower than the FVP control animals. Zinc, nickel, chromium, and lead concentrations were not measured in the FVP control animals.

In both the upland disposal and wetland creation field sites, plant and animal interrelations are developing. The extent of the populations and the species compositions of the ecosystems may require management procedures if unanticipated routes of contaminant mobility develop. Continued evaluation will better define the extent and nature of contaminant mobility at the FVP site, where contaminated estuarine dredged material was placed simultaneously in an upland and a wetland environment. This evaluation should include the contaminant mobility of organics into plants and animals in both environments. The development of the upland and wetland ecosystems at this site will be evaluated through September 1995.

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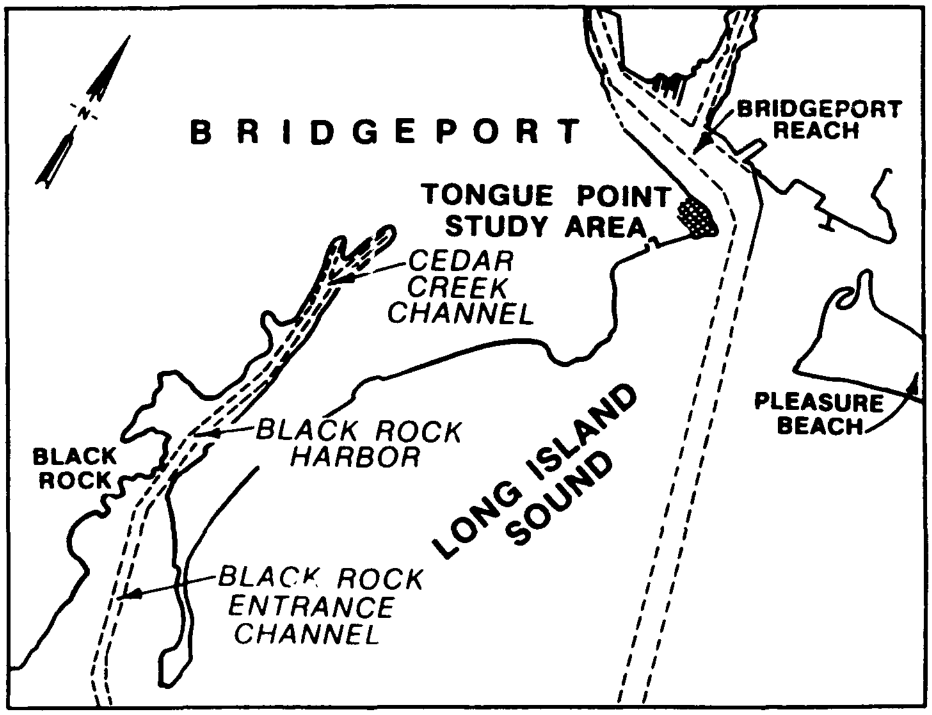


Figure 1. Location of FVP field site, Bridgeport, CT

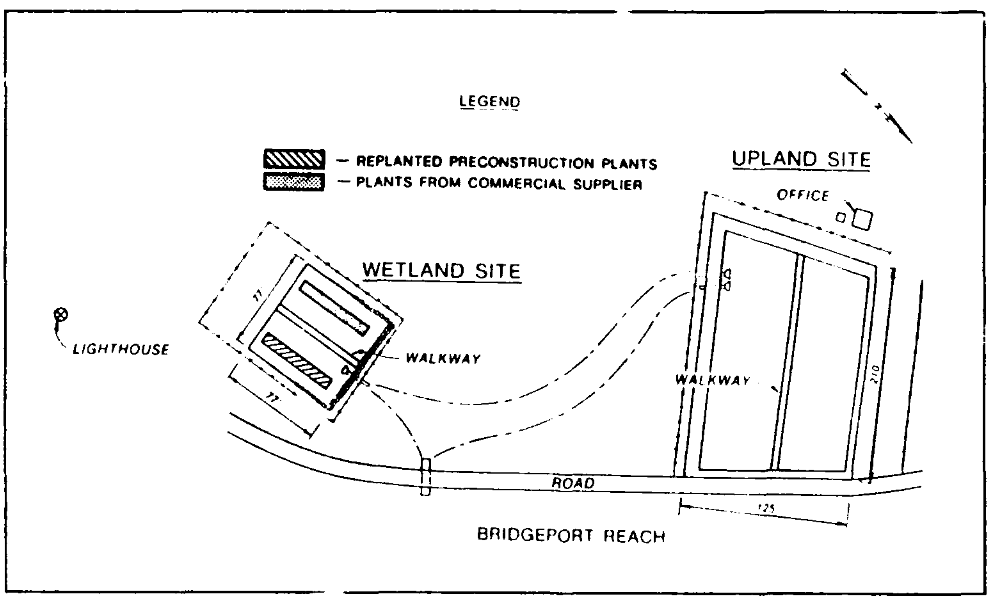


Figure 2. Schematic of FVP field site

a. 1985

b. 1989

Figure 3. Unamended Black Rock Harbor dredged material

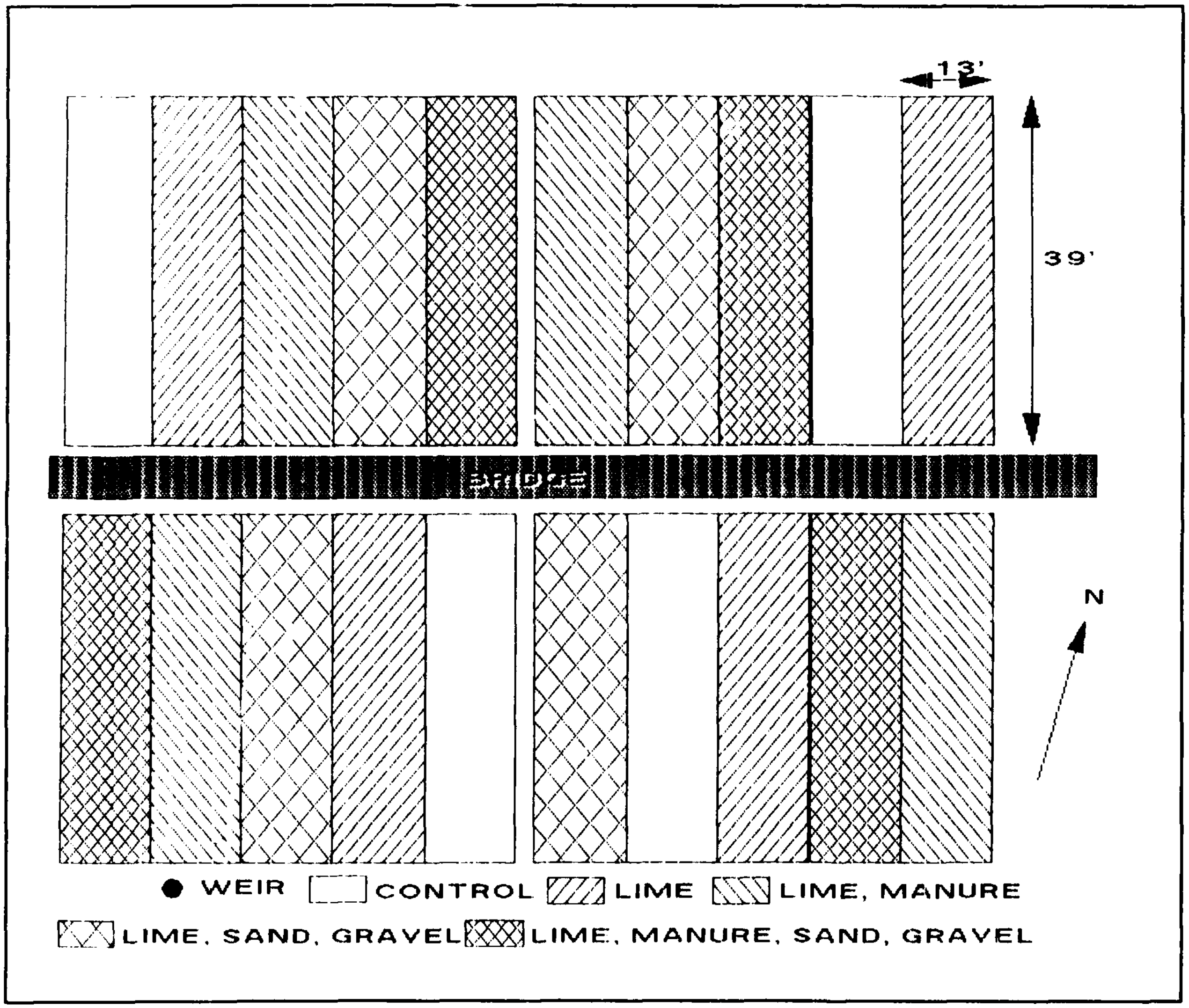


Figure 4. Schematic of upland site soil amendments (Table 4: Phase 1)

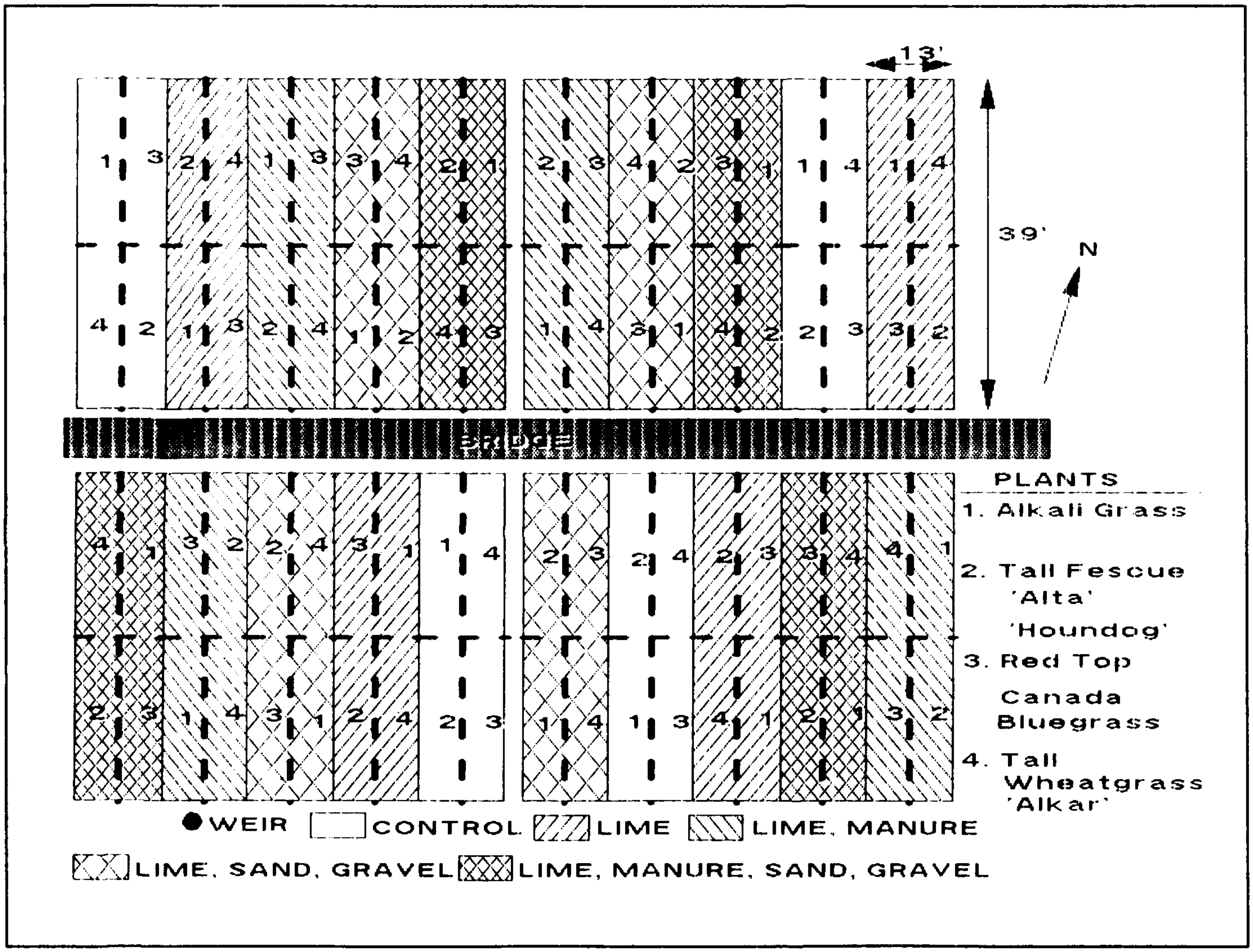


Figure 5. Schematic of upland site soil amendments and cool-season grass species (Table 4: Phases 2 and 3)

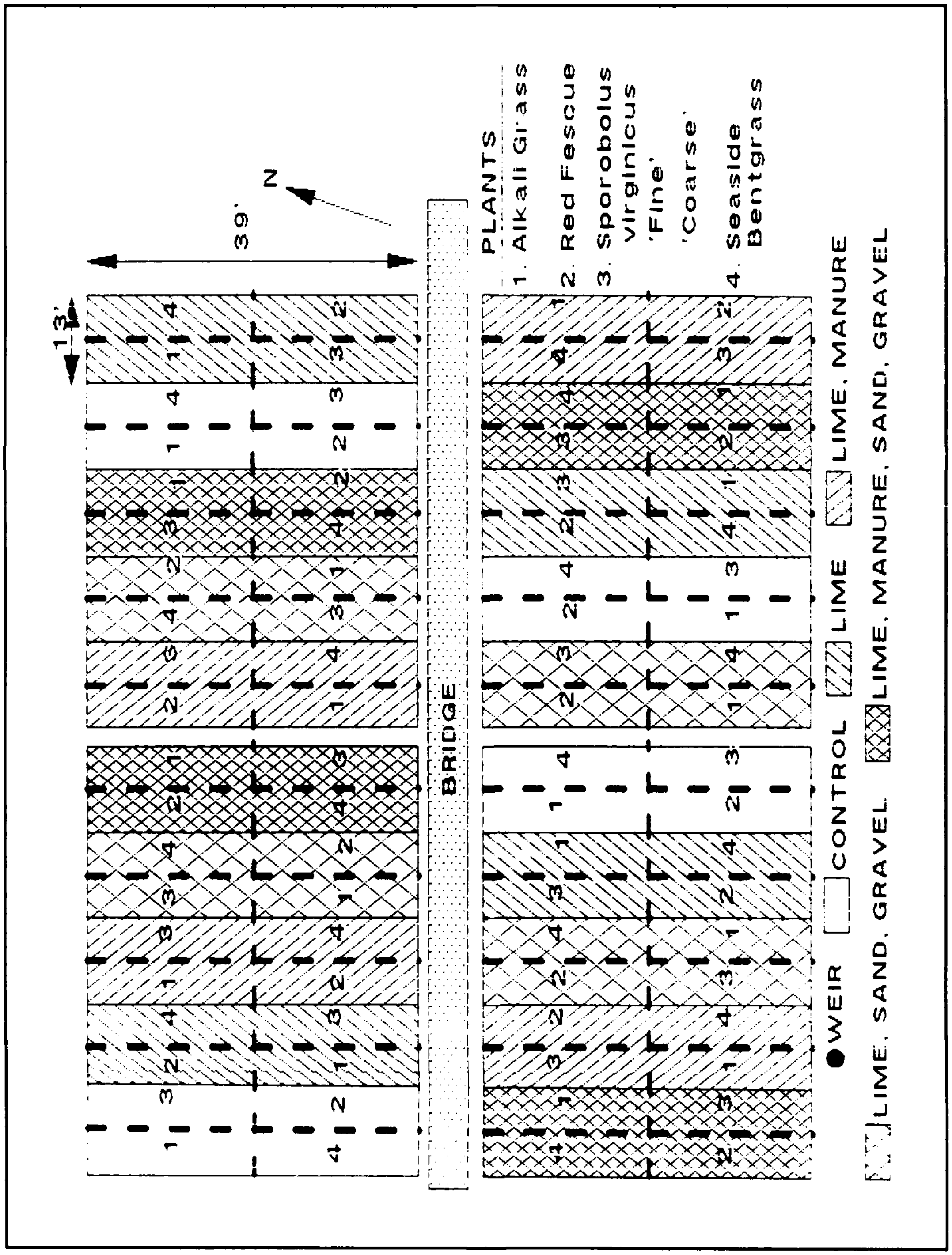


Figure 6. Schematic of upland site soil amendments and warm-season grass species (Table 4: Phase 4)

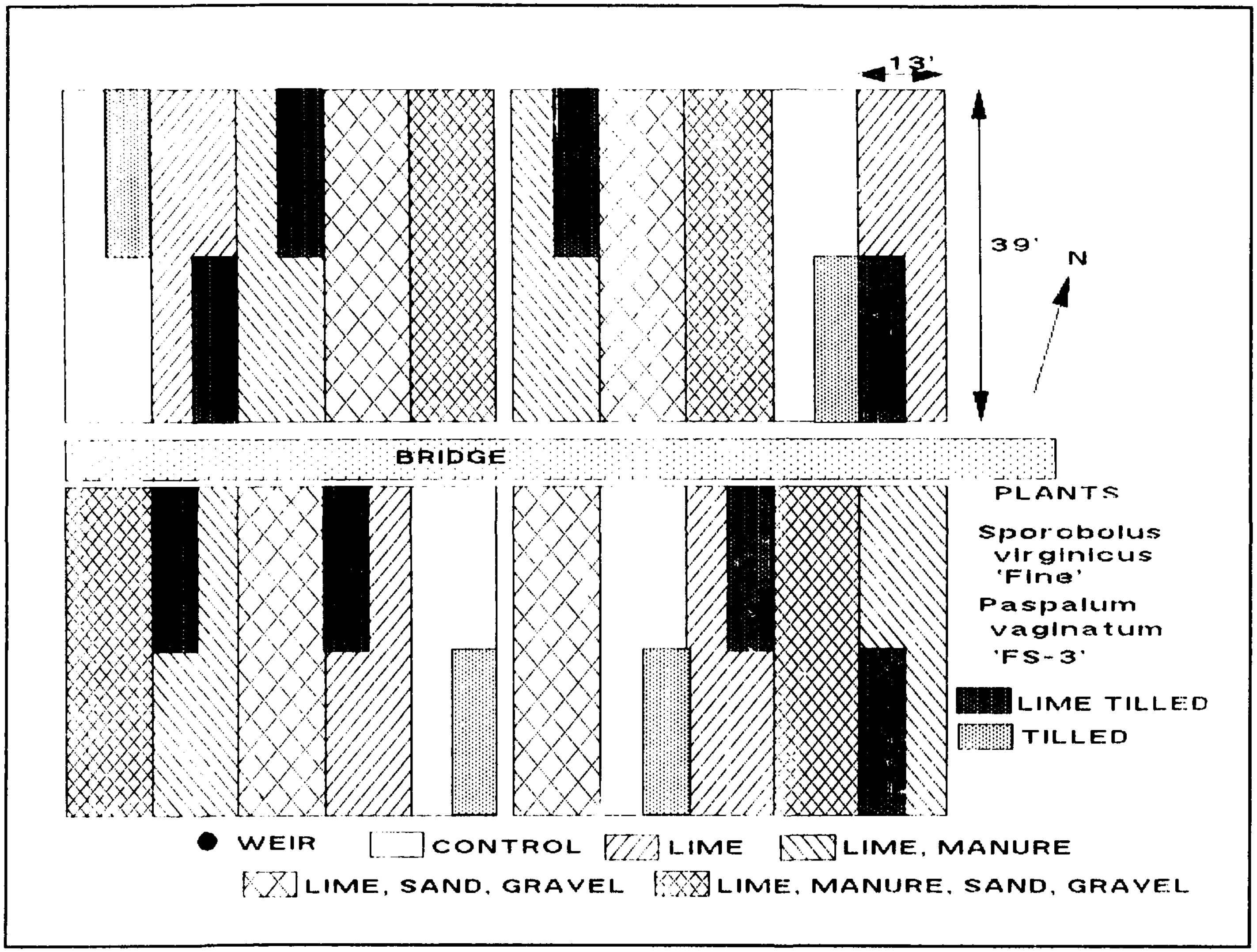
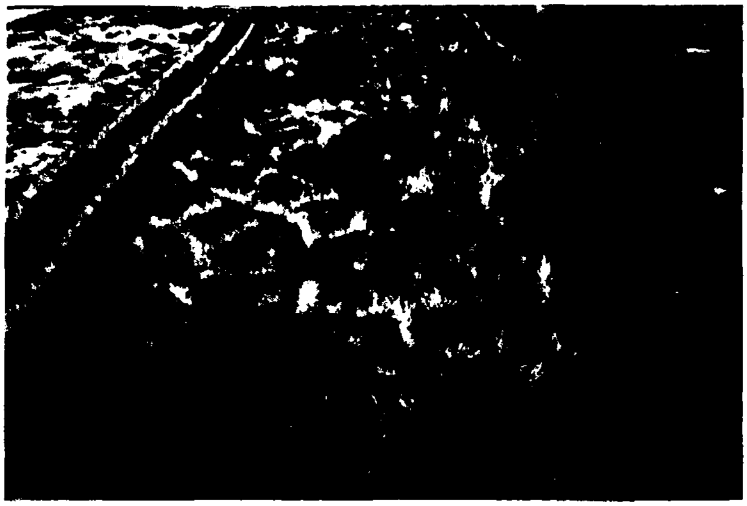


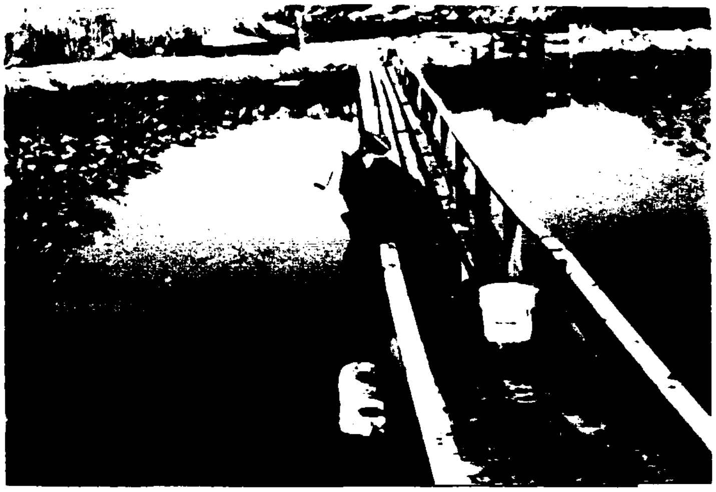
Figure 7. Schematic of upland site soil amendments and warm-season grass species (Table 4: Phases 5 and 6)



a. 1985

b. 1989

Figure 8. Black Rock Harbor dredged material amended with lime + manure + sand + gravel

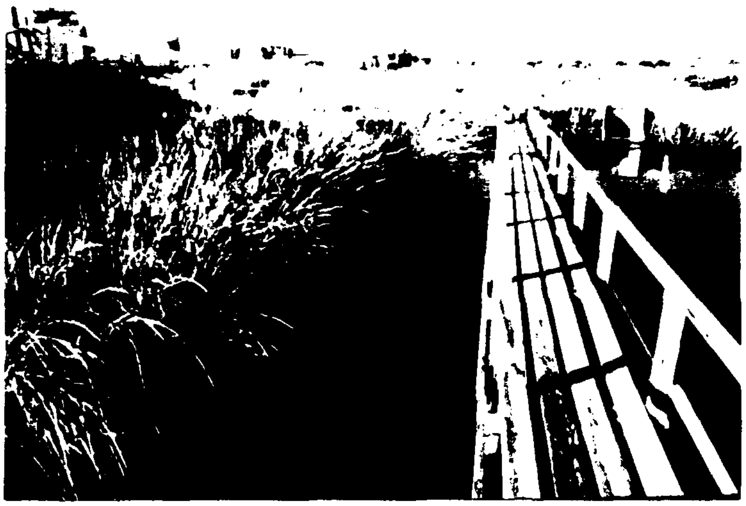


a. 1983

b. 1984

Figure 9. Wetland created with Black Rock Harbor dredged material (Sheet 1 of 3)

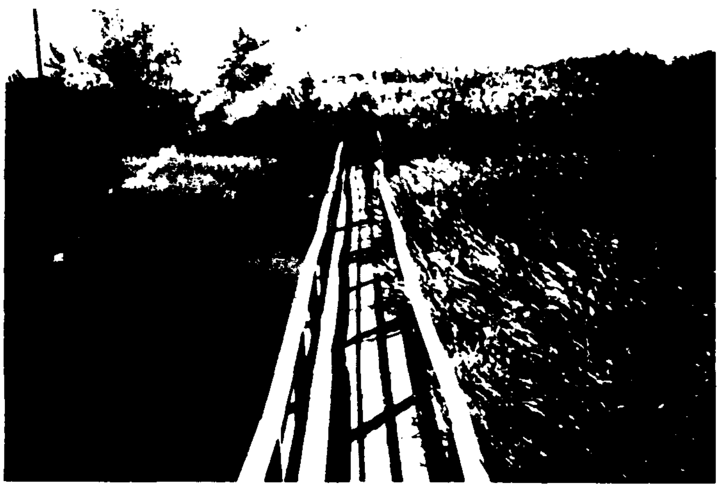
c. 1986



d. 1987

Figure 9. (Sheet 2 of 3)

e. 1988



f. 1989

Figure 9. (Sheet 3 of 3)

Figure 10. Native sandworms colonizing FVP wetland in 1986

Table 1
Chemical Analysis of Most Abundant Plant Species at FVP Field Site

Plant Species	Metals (μg/g)						
	Zn	Cd	Cu	Ni	Cr	Pb	Hg
Upland Species							
Phragmites australis (N = 2)[1]	29.2 (0.6)	0.13 (0.01)	8.9 (1.8)	5.7 (3.2)	0.71 (1.0)	1.4 (0.01)	0.003 (0.004)
Solanum dulcamara (N = 1)	46.8 (0.0)	1.33 (0.0)	19.6 (0.0)	30.8 (0.0)	2.7 (0.0)	6.4 (0.0)	0.018 (0.0)
Robinia pseudoacacia (N = 2)	38.6 (3.5)	0.48 (0.05)	10.7 (3.7)	20.5 (4.8)	2.17 (0.7)	3.7 (2.9)	0.03 (0.04)
Populus deltoides (N = 4)	688 (239)	4.85 (1.3)	15.6 (4.7)	27.3 (20)	0.04 (0.1)	4.3 (1.5)	0.01 (0.01)
Wetland Species							
Phragmites australis[2] (N = 7)	22.5 (9.5)	0.17 (0.1)	3.6 (1.2)	5.6 (2.9)	1.1 (1.7)	2.2 (0.8)	0.003 (0.01)
Solidago sempervirens[2] (N = 3)	178 (70)	1.29 (0.9)	14.0 (2.5)	16.0 (3.2)	1.4 (2.4)	2.6 (1.0)	0.0 (0.0)
Distichlis spicata[3] (N = 1)	36.2 (0.0)	0.02 (0.0)	4.5 (0.0)	4.5 (0.0)	0.0 (0.0)	1.2 (0.0)	0.0 (0.0)
Spartina patens[3] (N = 1)	16.0 (0.0)	0.18 (0.0)	6.1 (0.0)	3.4 (0.0)	6.7 (0.0)	1.4 (0.0)	0.0 (0.0)

[1] N = number of samples collected and analyzed; standard deviation is given in parentheses.
[2] High marsh with freshwater influence.
[3] Low marsh with tidal influence.

Table 2
Characterization of Black Rock Harbor Sediment

Parameter	Content[1]	Parameter	Content
Zn	1,307.1	Benzo(a)pyrene	3.9
Cd	22.4	Sum of PAHs	142.0
Cu	2,728.4	Oil and Grease	17,452.4
Ni	178.8	Chemical oxygen demand	232,880.0
Cr	1,651.0	Total organic carbon	54,104.0
Pb	397.8	Organic matter (percent)	19.8
Hg	2.0	$CaCO_3$ equivalent (percent)	1.0
As	22.9	Total sulfur (percent)	1.3
Fe	31,000.0	Wet sediment pH	7.6
PCB as Aroclor 1242	5.5	Dry sediment pH	6.6
PCB as Aroclor 1254	9.3	Sand (percent)	42.0
PP-DDD	0.9	Silt (percent)	47.0
Phenanthrene	5.0	Clay (percent)	11.0
Fluoranthene	6.3	Salinity (ppt)	28

1 Contaminant concentration units are expressed in micrograms per gram (dry weight) unless noted otherwise.

Table 3
Changes in Soil Conditions After Upland Disposal of Unamended and Amended Contaminated Estuarine Dredged Material

	Plots							
	Unamended Control				Amended[1]			
Parameter	10/83	11/85	6/86	10/89	10/83	11/85	6/86	10/89
Soil pH	7.6	3.2	3.2	3.4	7.6	NS[2]	NS	4.4
Salinity (ppt)	28	29	13	<1	28	29	13	<2
Organic matter (%)	19.5	NS[2]	NS	7.7	19.5	NS	NS	8.5

1 Lime + manure + sand + gravel.
2 No sample.

Table 4
Phases of Restoration Evaluated for Contaminated Estuarine Dredged Material Placed in Upland Disposal Environment

Phase 1: Application of Soil Amendments, September 1984	
1. Control	No amendments
2. Lime	28.2 metric tons /hectare (mt/ha)
3. Lime + sand + gravel	28.2 mt/ha, lime 13-cm surface layer, sand 6.6-cm surface layer, limestone gravel
4. Lime + manure	28.2 mt/ha, lime 112 mt/ha, horse manure
5. Lime + manure + sand + gravel	28.2 mt/ha, lime 112 mt/ha, horse manure 13-cm surface layer, sand 6.6-cm surface layer, limestone gravel
Phase 2: First Seeding of Cool-Season Grass Species, October 1984	
1. *Puccinellia distans* (alkali grass)	
2. *Festuca elatior* (tall fescue 'Houndog')	
3. *Agrostis alba* (redtop) + *Poa compressa* (Canada bluegrass)	
4. *Agropyron elongatum* (tall wheatgrass 'Alkar')	
Phase 3: Second Seeding of Cool-Season Grass Species, March 1985	
1. *Puccinellia distans* (alkali grass)	
2. *Festuca elatior* (tall fescue 'Alta')	
3. *Agrostis alba* (redtop)	
4. *Agropyron elongatum* (tall wheatgrass 'Alkar')	
Phase 4: First Seeding of Warm-Season Grass Species, June 1985	
1. *Puccinellia distans* (alkali grass)	
2. *Festuca rubra* (red fescue)	
3. *Sporobolus virginicus* 'Fine' *Sporobolus virginicus* 'Coarse'	
4. *Agrostis tenuis* (seaside bentgrass)	
Phase 5: Rototilling (to a depth of 15 cm) on Selected Plots, June 1986	
1. Rototilled one quarter of control unamended plots	
2. Reapplied and rototilled lime (56.4 mt/ha) on 1/4 of lime plot	
3. Reapplied and rototilled lime (56.4 mt/ha) on 1/4 of lime + manure plot	
Phase 6: Planted Rototilled Portions of Selected Plots, June 1986	
1. *Paspalum vaginatum* 'FS-3'	
2. *Sporobolus virginicus* 'Fine'	
Seeding Rates/Tolerant(s)	
Puccinellia distans (alkali grass)	11 kg/ha/salt
Festuca elatior (tall fescue 'Houndog')	32 kg/ha /acid, salt
Agrostis alba (redtop)	11 kg/ha /acid, salt
Poa compressa (Canada bluegrass)	32 kg/ha/acid
Agropyron elongatum (tall wheatgrass 'Alkar')	23 kg/ha/salt
Festuca rubra (red fescue)	32 kg/ha/metal
Agrostis tenuis (seaside bentgrass)	11 kg/ha/salt
Plugging Rates/Tolerant(s)	
Paspalum vaginatum 'FS-3'	1 per sq ft/salt
Sporobolus virginicus 'Fine'	1 per sq ft/salt
Sporobolus virginicus 'Coarse'	1 per sq ft/salt

Table 5
Influence of Soil Amendments on Growth, Diversity, and Percent Cover of Plant Species Colonizing Estuarine Dredged Material Placed in Upland Disposal Environment, 1989

Treatment	Percent Cover							
	Plant Species[1]							Total
	AGREL	AGRAL	ARTVV	DIGSA	PHRAV	POACO	OTHER	
Control (Tilled[2])	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Lime (Tilled)	0 0	36 85	1 1	6 4	4 1	1 1	3 4	51 96
Lime + manure (Tilled)	0 0	2 94	0 5	0 0	25 0	0 0	1 0	28 99
Lime + sand + gravel	0	45	0	2	3	0	0	50
Lime + manure + sand + gravel	4	58	1	9	22	2	1	97

1 Plant species codes are defined as follows:

AGREL = *Agropyron elongatum* (tall wheatgrass)
AGRAL = *Agrostis alba* (redtop)
ARTVV = *Artemisia vulgaris* (common sage)
DIGSA = *Digitaria sanguinalis* (hairy crabgrass)
PHRAV = *Phragmites australis* (common reed)
POACO = *Poa compressa* (Canada bluegrass)
OTHER = *Aster pilosus* (hairy aster)
= *Daucus carota* (wild carrot)
= *Epilobium coloratum* (cinnamon willow herb)
= *Erechtites hieracifolia* (fire weed)
= *Lactuca scariola* (prickly lettuce)
= *Linaria vulgaris* (butter'n eggs)
= *Oenothera biennis* (evening primose)
= *Phleum pratense* (timothy grass)
= *Puccinellia distans* (alkali grass)
= *Rumex crispus* (curly dock)
= *Solidago altissima* (tall goldenrod)
= *Solidago sempervirens* (seaside goldenrod)
= *Verbascum thapsus* (woolly mullein)

2 In 1986, one quarter of the plot was rototilled. The lime and lime + manure plots received an additional application of lime.

Table 6
Plant Content (μg/g) of Selected Metals in Leaf Tissue of *S. virginicus* Grown in Sediment from Black Rock Harbor

Metal	Greenhouse: Original Sediment: Flooded	Greenhouse: Original Sediment: Upland	Greenhouse: Washed Sediment: Upland	Field: Wetland (Flooded)	Field: Upland
Zn	26.2c[1]	40.1b	86.3a	No survival	66.0ab
Cd	0.857b	0.684b	1.34ab		2.22a
Cu	10.7b	24.3ab	34.5a		19.8b
Ni	6.82bc	22.8a	13.4b		5.38c
Cr	<0.025c	8.64a	0.506b		7.64a
Pb	<0.013b	<0.013b	<0.013b		1.56a

Source: Folsom et al. 1988 (Table 13).

[1] Means within a row followed by the same letter are not significantly different at P = 0.10 using the Least Significant Difference method.

Table 7
Tissue Contaminant Contents (μg/g, dry weight) of *A. alba* Plants Growing on FVP Upland Disposal Site

Contaminant	1988		1989	
Amended – Lime				
	N = 3		**N = 4**	
Zn	85.4	(76.3)[1]	138.4	(40.1)
Cd	1.1	(0.1)	1.5	(0.9)
Cu	15.0	(1.8)	92.2	(80.0)
Ni	13.4	(4.0)	11.9	(5.1)
Cr	6.7	(0.8)	26.5	(9.2)
Pb	3.1	(1.7)	6.2	(4.0)
Hg	0.1	(0.03)	0.1	(0.01)
Amended – Lime + Manure				
	N = 3		**N = 3**	
Zn	105.0	(27.5)	124.9	(32.2)
Cd	1.0	(0.3)	1.1	(0.8)
Cu	21.6	(8.0)	15.3	(5.4)
Ni	12.8	(4.0)	15.2	(4.4)
Cr	11.2	(3.3)	10.6	(4.0)
Pb	4.6	(1.4)	6.4	(3.7)
Hg	0.1	(0.01)	0.05	(0.01)
Amended – Lime + Sand + Gravel				
	N = 1		**N = 4**	
Zn	110.1	(0.0)	128.5	(57.8)
Cd	1.7	(0.0)	1.5	(0.8)
Cu	23.6	(0.0)	101.0	(77.0)
Ni	13.7	(0.0)	13.5	(5.3)
Cr	11.1	(0.0)	34.8	(27.6)
Pb	6.6	(0.0)	11.0	(7.9)
Hg	0.2	(0.0)	0.07	(0.03)
Amended – Lime + Manure + Sand + Gravel				
	N = 1		**N = 2**	
Zn	111.0	(0.0)	102.5	(26.0)
Cd	1.1	(0.0)	1.4	(0.06)
Cu	140.9	(0.0)	79.9	(73.1)
Ni	13.7	(0.0)	11.9	(1.4)
Cr	24.4	(0.0)	36.0	(28.5)
Pb	8.6	(0.0)	6.5	(6.6)
Hg	0.1	(0.0)	0.1	(0.02)

[1] Standard deviation given in parentheses.

Table 8
Demonstrated Effects of Contaminants on Plants (Contaminant Content, mg/kg leaves)

Contaminant	Normal[1]	Critical Content[2]	10% Yield Reduction[2]	25% Yield Reduction[3]	Phytotoxic[1]
Arsenic	0.1-1	—	—	—	3-10
Boron	775	—	—	—	75
Cadmium	0.1-1	8	15	Varies	5-700
Cobalt	0.01-0.3	—	—	—	25-100
Chromium (III), oxides	0.1-1	—	—	—	20
Copper	3-20	20	20	20-40	25-40
Fluorine	1-5	—	—	—	—
Iron	30-300	—	—	—	—
Manganese	15-150	—	—	500	400-2,000
Molybdenum	0.1-3.0	—	—	—	100
Nickel	0.1-5	11	26	50-100	500-1,000
Lead	2-5	—	—	—	—
Selenium	0.1-2	—	—	—	100
Vanadium	0.1-1	—	—	—	10
Zinc	15-150	200	290	500	500-1,500

Source: Lee et al. 1991 (Table C7).
1 From Chaney (1983).
2 From Davis, Beckett, and Wollan (1978); Davis and Beckett (1978); and Beckett and Davis (1977).
3 From Chaney et al. (1978).

Table 9
Influence of Soil Amendments on Abundance and Diversity of Invertebrate Animals Colonizing Estuarine Dredged Material Placed in Upland Disposal Environment, 1989

	Animal Taxon[1]								
Treatment	**GAS**	**ORT**	**DIP**	**HYM**	**COL**	**COP**	**ARA**	**OTHER**	**Total**
Control	0	4	10	9	1	2	6	0	32
Lime	42	24	22	27	61	13	13	2	204
Lime + manure	35	26	9	24	43	18	20	0	175
Lime + sand + gravel	26	9	9	15	51	15	24	2	151
Lime + manure + sand + gravel	6	12	4	124[2]	10	35	29	3	223

[1] Taxon codes are defined as follows:
GAS = Mollusca, Class Gastropoda (slugs and snails)
ORT = Insecta, Order Orthroptera (crickets and grasshoppers)
DIP = Insecta, Order Diptera (flies)
HYM = Insecta, Order Hymenoptera (wasps, bees, and ants)
COL = Insecta, Order Collembola (springtails)
COP = Insecta, Order Coleoptera (beetles)
ARA = Arthropoda, Class Arachnida (spiders, ticks, and harvestmen)
OTHER = Crustacea (woodlice)
Insecta, Hemiptera (bugs)
Insecta, Lepidoptera (butterflies and moths)
Insecta, Homoptera (leafhoppers)

[2] One trap was near an anthill.

Table 10
Biomass Production (g/m^2) of *S. alterniflora* in FVP Wetland Created with Black Rock Harbor Dredged Material

Source	**Natural Marsh**	**1986**	**1987**	**1988**	**1989**
Environmental concern (St. Michaels, MD)	627[1]	511	798	226	297
Native transplants	627[1]	311	535	337	468

[1] From Simmers et al. (1981).

Table 11
Leaf Tissue Content of Selected Heavy Metals in *S. alterniflora* Grown in Laboratory and the Field and Predicted from DTPA Sediment Extraction Data (Using the Equations of Lee, Folsom, and Bates 1983)

Heavy Metal	Concentration, µg/g				Analysis of Variance	
		Field-Grown				
	Laboratory (N = 4)	1985 (N = 7)	1986 (N = 7)	Predicted by DTPA (N = 3)	F	P
Zn	12.1[1] (1.26) C[2]	13.5 (5.03) BC	<u>19.2 (7.05) B</u>[3]	41.7 (2.44) A	15.89	0.0001
Cd	<u>0.041 (0.007) B</u>	0.021 (0.046) C	<0.0025 (0) C	0.196 (0.026) A	22.64	0.0001
Cu	4.02 (1.38) A	5.65 (1.74) A	7.48 (5.55) A	2.70 (0.080) A	2.20	0.1486
Ni	0.954 (0.388) A	4.23 (6.13) A	0.743 (0.675) A	0.346 (0.0098) A	2.26	0.1183
Cr	0.274 (0.322) B	<u>10.4 (8.21) A</u>	6.17 (5.49) AB	1.63 (0.093) AB	2.91	0.0648
Pb	0.237 (0.441) B	<u>3.45 (4.90) A</u>	0.945 (0.892) AB	0.70 (0.0) AB	3.18	0.0507

Source: Simmers et al. 1989 (Table 4).
[1] Values are means (and standard deviations).
[2] Letters in the row indicate statistical groupings of means (square root transformation, Waller-Duncan k-ratio t-test).
[3] Elevated mean concentrations are underlined.

Table 12
Tissue Contaminant Contents (µg/g) of *S. alterniflora* Grown on a Contaminated Estuarine Dredged Material from Black Rock Harbor

Heavy Metal	Natural Marsh[1] N = 20[2]	Field Collected				
		Prior,[3] N = 7	1985, N = 7	1986, N = 7	1988, N = 8	1989, N = 9
Zn	44.3 (24.8)	22.5 (9.5)	13.5 (5.0)	<u>19.2</u>[4] (7.1)	21.1 (4.3)	20.3 (8.2)
Cd	0.20 (0.19)	0.17 (0.11)	0.02 (0.05)	<0.003 (0.0)	0.25 (0.05)	0.23 (0.03)
Cu	7.16 (2.16)	3.62 (1.18)	5.65 (1.74)	7.48 (5.55)	16.5 (8.9)	14.0 (13.1)
Ni	2.47 (1.76)	5.64 (2.90)	4.23 (6.13)	0.74 (0.68)	1.1 (0.4)	1.7 (0.7)
Cr	3.41 (1.8)	1.11 (1.70)	<u>10.4</u> (8.2)	6.17 (5.5)	5.7 (3.4)	6.3 (3.9)
Pb	4.85 (6.5)	2.17 (0.80)	<u>3.45</u> (4.9)	0.95 (0.9)	3.4 (2.0)	3.8 (3.0)
Hg	0.027 (0.02)	0.003 (0.01)	—	—	0.02 (0.003)	0.02 (0.007)

[1] From Simmers et al. (1981).
[2] N = number of samples collected and analyzed; standard deviation in given in parentheses.
[3] Samples collected prior to construction (from Simmers et al. 1989).
[4] Elevated mean concentrations are underlined.

Table 13
Evaluation o. ..88 and 1989 *S. alterniflora* Data Using the FVP Laboratory and Field Results

Heavy Metal	Concentrations, µg/g[1]				
		Field-Grown			
	Laboratory	1985	1986	1988[2]	1989[2]
Zn	Not elevated	Possibly elevated	Elevated	Elevated	Elevated
Cd	Elevated	Not elevated	Not elevated	Elevated	Elevated
Cu	Not elevated	Not elevated	Not elevated	—[3]	—
Ni	Not elevated	Not elevated	Not elevated	—	—
Cr	Not elevated	Elevated	Possibly elevated	Not elevated	Possibly elevated
Pb	Not elevated	Elevated	Possibly elevated	Possibly elevated	Elevated

[1] "Not elevated" implies that *Spartina* concentrations from this wetland test are not statistically geater than concentrations from any remaining wetland test; "elevated" implies that *Spartina* concentrations from this wetland test are statistically greater than concentrations from at least one remaining wetland test; and "possibly elevated" implies that *Spartina* concentrations from this wetland test are not statistically different from concentrations from the two remaining wetland tests. However, concentrations from the two remaining tests are statistically different (i.e., one is elevated and the other is not).
[2] The 1988 and 1989 *Spartina* concentrations are evaluated using the criteria above. (That is, in Table 11, the 1986 mean zinc concentration, 19.2 µg/g, is "elevated." Since the 1988 mean zinc concentration exceeds this value, this concentration is given the same designation as the 1986 mean zinc concentration.)
[3] Cannot be determined.

Table 14
Tissue Contaminant Contents (µg/g) of Snails (*Ilyanassa obsoleta*) Exposed to Contaminated Estuarine Dredged Material

Parameter	Control Sand,[1] N = 1[2]	1988, N = 1	1989, N = 2
Zn	NS[3]	878.18	675.2 (31.9)[4]
Cu	2,913	1,335.68	1,881.7 (574)
Cd	8.6	2.93	3.6 (0.5)
Ni	NS	8.79	13.3 (1.6)
Cr	NS	9.02	29.7 (16.0)
Pb	NS	10.21	16.1 (5.3)
Hg	0.26	0.08	0.1 (0.05)

[1] From Simmers et al. 1989 (Table 9).
[2] One composite sample.
[3] No sample.
[4] Standard deviation given in parentheses.